

TITLE:       **H-BRIDGE WITH SINGLE LEAD FRAME**

FIELD OF THE INVENTION

[0001]       This invention relates to a d-c motor control circuit and more specifically relates to a novel H-bridge driver for controllably driving loads such as d-c motors.

BACKGROUND OF THE INVENTION

[0002]       Control circuits are well known for driving d-c motors. H-bridge circuits are commonly employed which employ two high side MOSFETs and two low side MOSFETs in which each high side device is in series with a respective low side device. The nodes between the pairs of high side and low side devices, hereinafter M1 and M2 respectively, are connected to the motor terminals; the drains of each of the high side devices are connected to a d-c source such as a battery, hereinafter  $V_{cc}$ , and the sources of each of the low side devices are connected to ground (hereinafter GND).

[0003]       A control circuit is then provided to turn the high side and low side devices on and off to drive current through the motor windings in directions to cause rotation of the motor rotor in a clockwise or counterclockwise direction.

[0004]       The MOSFETs used for such circuits are commonly individually mounted as discrete devices; and the control circuits for controlling their conduction have also been formed of discrete circuits or combinations of several integrated circuits and discrettes. Further, complicated programmed circuits have also been necessary to the circuit control. All of this increases complexity and cost and reduces reliability of the control.

[0005] It would be desirable to reduce the component count of such circuits; and to simplify their operation and to avoid the need for programmed control functions.

#### BRIEF SUMMARY OF THE INVENTION

[0006] In accordance with the invention, a novel fully protected dual high side switch IC is provided with two additional discrete low side switches. The two high side switches and the control IC for controlling their operation may be contained on a common heat sink in a single plastic package having suitable connection pins for connection to the d-c source, ground, the motor terminals and the microcontroller which commons particular motor operations. Pins are also provided for an RC control circuit which controls soft start independently of signals from the microcontroller.

[0007] The single high side package drives and controls the entire H-bridge circuit, and contains a number of novel features.

[0008] The input signals IN1 and IN2 to the two high side FET drivers to be later described are also shown for explanatory purposes, as applied to the two high side FETs (in Figure 1) and operate to select the motor operation modes and provide the control within each mode. First a novel self adaptive shoot thru prevention circuit (during turn off) is provided to prevent the simultaneous conduction of a series connected (half-bridge) high side MOSFET and low MOSFET. In accordance with this feature, the low side driver circuits are contained in the integrated control circuit mounted with the high side devices. The low side FETs both always normally conduct to lock the motor when the circuit is off. To turn off, the high side MOSFETs are turned off by IN1 or IN2 which turns on the low side driver circuit of its respective low side FET to turn it on before the slower high side MOSFET turns fully off, particularly when its output voltage reaches and

exceeds a small value, for example, 2 volts. More specifically, to turn off a high side MOSFET, the high side FET is turned off and the circuit waits until its output voltage is less than about 2 volts. The low side FET which is off is then turned on to lock the motor load. Thus, shoot thru protection is adaptively provided without the conventional dead-time control circuit.

[0009] Second, a novel soft start sequence is provided each time the motor restarts, as selected by the IN1 and IN2 signals. The soft start circuit employs a PWM sequence which cycles a corresponding one of the low side switches to which current is steered by one of the high side switches (MOSFETs). This limits motor in rush current. The soft start sequence is operated (programmed) by a simple RC circuit and is automatically reset after starting.

[0010] Third, the novel circuit provides over current(short-circuit) and over temperature (overload) protection under the control of the IC in the high side MOSFET package. These protective functions are carried out by current sensors and thermal sensors on the high side MOSFETs, which are "IPS" switches, and provide a status feed-back to the microcontroller to call for shut-down. The protective circuit is then reset when IN1 and IN2 are both low (or zero).

[0011] Fourth, a number of other functions are carried out within the single control IC, which are selected by the combinations of signals IN1 and In2; for example, under-voltage lockout; motor braking, temperature protection and the diagnostic feedback.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Figure 1 is a diagram of the H-bridge circuit of the invention, and a d-c motor driven thereby.

[0013] Figure 1A is a cross-section of the novel high side driver package of the invention.

[0014] Figure 1B is a cross-section of another embodiment of the package in which all 4 MOSFETs are in a single package.

[0015] Figure 1C shows a top view of a preferred topology for arranging the high side MOSFETs and the IC of Figure 1A.

[0016] Figure 1D shows a cross-section like that of Figure 1A in which a conductive lead frame support is provided.

[0017] Figure 2 is a perspective view of one of the low side packages of Figure 1.

[0018] Figure 3 is a top view of Figure 2.

[0019] Figure 4 is a perspective view of the package of Figure 1A.

[0020] Figure 5 is a top view of Figure 4.

[0021] Figure 6 shows the circuit of Figure 1 carried out with the packages of Figures 2, 3, 4 and 5.

[0022] Figure 7 is a circuit diagram of the high side packages of Figure 2 including the control IC and other control circuits.

[0023] Figure 8 is a diagram similar to that of Figure 6 showing a particular load circuit and an RC timing circuit for the soft start circuit.

[0024] Figure 9 shows portions of the shoot-thru prevention circuit in the control IC.

[0025] Figure 10 shows portions of the soft start circuit.

[0026] Figure 11 shows portions of the logic control for sleep mode and RC reset.

[0027] Figure 12 shows portions of the shut down circuits in the IC control.

[0028] Figure 13 to 18 show various operation characteristics of the circuits of Figures 1 to 12.

### DETAILED DESCRIPTION OF THE DRAWINGS

[0029] Referring first to Figure 1, there is shown an H bridge circuit made in accordance with the invention. Figure 1 also shows the bridge circuit of the invention arranged to drive a d-c motor 30, although the novel bridge can be used in other applications, for example, for driving linear solenoids and other loads.

[0030] The bridge of Figure 1 consists of first and second high side MOSgated devices 31 and 32, shown as N channel vertical conduction MOSFETs. Note that the invention can be carried out with other MOSgated devices such as IGBTs and could be carried out with P channel devices. Both MOSFETs 31 and 32 can be mounted with their drain electrodes on a common heat sink such as a conductive diced frame pad, or a conductive trace on a PCB board, and can be contained in a single package 33, shown as a dotted line box. Package 33 is shown in more detail in Figures 4, 5 and 6 which will be later described.

[0031] The bridge of Figure 1 next contains two low side MOSgated devices 40 and 41. Each of MOSgated devices 40 and 41 are also shown to be N channel MOSFETs, and are separately packaged in discrete packages 42 and 43 respectively (Figures 2, 3 and 6).

[0032] Thus, low side MOSFETs 42 and 43 may be housed in 8 lead SOIC packages as shown in Figures 2, 3 and 6 and may, for example, each be device type IRFL7484, available from the International Rectifier Corporation, located in El Segundo California and the assignee of this application. This is a 6.8 m $\Omega$ , 40 volt device. The ratings can be changed as needed. Figures 2, 3 and 6 show the pin-outs of device 42 and 43 (Figure 6), consisting of the source S, drain D and gate G terminals.

[0033] Package 33 containing high side MOSFETs 31 and 32 is shown in Figures 4, 5 and 6 which shows the pin outs of the package. The pin or lead definitions are as follows and their functions will be later described in greater detail:

Vcc	Positive power supply
M1	Motor 1 output (high side source - leg 1)
M2	Motor 2 output (high side source - leg 2)
G1	Gate 1 drive output (low side gate - leg 1)
G2	Gate 2 drive output (low side gate - leg 2)
Gnd	Power supply return
IN1	Logic input 1 (leg 1 Cdt./mode)
IN2	Logic input 2 (leg 2 Cdt./mode)
Dg	Diagnostic output (open drain)
Vrc	Voltage ref. Output (soft-start RC)
SS	RC soft-start input (the voltage on this input drives the switching duty cycle)

[0034] The source electrodes 27 and 28 of devices are preferably mounted on a common conductive support, for example, the main pad of a conductive copper or copper alloy lead frame, as shown in figure 1D. If lead frame is used, the pins described above will be integral with the lead frame before separation of the lead frame elements.

[0035] Figure 1A shows another possible support arrangement for MOSFETs 31 and 32 on a support circuit board 20 instead of a lead frame. Board 20 has a copper coatings 21 and 22 and the drain electrodes 23 and 24 of MOSFETs 31 and 32 respectively are conductively connected to conductive layer 21. The source electrodes 27 and 28 of devices 31 and 32 respectively in Figures 1A and 1D are connected to terminals M1 and M2 which protrude beyond the boundaries of insulation housing 33. The source electrodes 27 and 28 of MOSFETs 31 and 32 respectively are connected to the external ground pins GND. The gate control electrodes of MOSFETs are then connected as by wire bonding to a suitable control

IC which will be later described and which is also supported on board 20. The control IC can be mounted to the layer 21 (or conductive lead frame in Figure 1D) by an insulation die attach medium.

[0036] Figure 1B shows a modification of Figures 1A and 1D wherein the low side MOSFETs 40 and 41 are mounted atop MOSFETs 31 and 32 respectively with their drains adhesively and electrically connected to the sources of MOSFETs 31 and 32. Thus, the entire driver is contained within a single package in Figure 1B. Note that the arrangement of Figure 1B can be used with the lead frame support of Figure 1D.

[0037] Figure 1C shows a top view of a further preferred embodiment of the arrangement of MOSFETs 31 and 32 and the control IC.

[0038] The circuit of Figures 1 and 6, as will be later described is a fully protected dual high side switch that features a whole H-bridge control. The protective circuits may be integrated into the package 33, with the two low side MOSFETs 40 and 41. The inrush current of a d-c motor load 30 may be limited and the motor 30 driven in both directions with a braking mode, without the need for external power management. Current protection (short circuit) and temperature responsive shut down due to overload may also be provided as later described.

[0039] The high side switches 31 and 32 provide direction capability and the H-bridge protection. The on/off state of MOSFETs 31, 32, 40 and 41 are shown for motor rotation in the direction of arrow 50 in Figure 1 as one example of the control function. The low side MOSFETs 40 and 41 bring flexibility to the circuit by offering high frequency switching ability. Therefore, hard start-up of the motor can be avoided by a smooth low stress speed ramp up, as will be later described.

[0040] Before describing the control circuitry dealing with sleep mode, shoot-thru protection, soft start, and thermal protection, it is useful to understand the turn on and turn off sequences for MOSFETs 31, 32, 40 and 41.

[0041] This operation is best understood from the following "Truth Table" for 6 different control modes of motor 30:

IN1	IN2	MODES	DG	FET31	FET40	FET32	FET41	SS Reset
L	L	Stand-by with braking-sleep mode	H	OFF	ON	OFF	ON	ON
L	H	Forward rotation (normal operation)	H	OFF	ON	ON	OFF	OFF
L	H	Forward rotation (protection triggered)	L	OFF	ON	OFF	OFF	OFF
H	L	Reverse rotation (normal operation)	H	ON	OFF	OFF	ON	OFF
H	L	Reverse rotation (protection triggered)	L	OFF	OFF	OFF	ON	OFF
H	H	Stand-by without braking	H	OFF	OFF	OFF	OFF	ON

[0042] In the above table, it will be later shown that in the "sleep mode", all protection circuits are reset; and that MOSFET 40, while shown "ON" in reverse rotation ("normal operation" and "protection triggered") that the low side part is switching.



[0043] Note that in the sleep mode (with the motor braking on) both low side devices should be ON, but a novel control circuit using minimum current drain for keeping them in this condition is provided.

[0044] Figure 7 is a block diagram of the circuitry, including control circuits contained within package 33. Thus, MOSFETs 31 and 32 are provided with respective shoot- thru protection circuits 61 and 62 respectively and with over current shut down circuits 63 and 64 respectively. A logic control and status feedback circuit 65 is provided to control the overcurrent and shoot- thru protection circuits. Finally, a soft start control circuit consisting of an oscillator 70, comparator 71 which switches relative to the reference REF derived from pin  $V_{RC}$ , and a soft start reset switch 72 is provided and is under the control of circuit 65. These various components may be integrated in one or more IC chips within package 33.

[0045] The architecture of the circuit of Figure 7 embodies several basic features:

[0046] First, each leg of the H-bridge, (including low side devices 40 and 41 of Figure 6) are totally independent of one another. Each features its own current protection and shoot-thru circuitry. Thus, no "diagonal" command among the four MOSFETs is needed.

[0047] Second, the normal quiescent state of the low side MOSFETs 40 and 41 is ON. Since each leg of the bridge is independent, the input signals IN(1) and IN(2) control or drive the high side MOSFET 31 or 32 and low side MOSFET 40 and 41 respectively. That is, the low side devices 40 and 41 are driven by gate drivers 75 and 76 respectively which are, in turn, driven from shoot-thru protect circuits 61 and 62 of the high side FETs 31 and 32 respectively.

[0048] Regarding the shoot-thru protection, as stated before, both low side MOSFETs will be normally ON (for braking) when the circuit is off. Therefore, care must be taken to turn the proper low side device on before its series high side

device is turned off. In accordance with the invention, the appropriate low side MOSFET must turn on when the node to its series high side device is greater than some given value, for example, two volts.

[0049] Third, the soft start circuitry of oscillator 70 and comparator 71 bring a gradually increasing pulse width modulated signal to both low side MOSFETs 40 and 41 without consideration of the direction of current flow in the high side MOSFETs 31 and 32. Therefore, the pulse width modulation circuitry is almost independent and offers great flexibility to extended operational requirements, for example, control of motor speed or torque.

[0050] Each of the above features are chosen for safe bridge operation or to increase independence among the IC functions without the need for any H bridge logic circuitry. However, other functions related to the IC may still be implemented including: undervoltage lockout; temperature protection; and diagnostic feedback. These functions may all be gathered in the logic control and status IC 65.

[0051] The ultimate control of the circuit of Figures 6 and 7 is derived from a micro controller. Thus, in Figure 8, a micro controller 80 is provided, having a diagnostic feedback terminal or pin 81 connected to the DG pin on package 33. The micro controller also provides a clockwise control signal output pin 82 and a counter clockwise rotation pin 83 connected to IN(1) pin and IN(2) pin respectively on package 33. These inputs will turn MOSFETs 31, 32, 40 and 41 on and off in the necessary sequence to cause motor 30 to rotate clockwise or counter clockwise respectively. In a typical application, motor 30 may move rack 85 to the left or right until reaching stop switches 86 or 87 respectively to stop motor operation past a given limit.

[0052] Figure 8 also shows resistor 90 and capacitor 91 which are connected to the RC pin and the SS (soft start) pin on circuit 33. These components control and program the soft start sequence which will be later described.

[0053] Figure 9 shows the novel structure employed for the shoot thru protection circuits 61 and 62 of Figure 7. Traditional shoot-thru control circuits employ an intentional dead time between the conduction of the series high side and low side devices. The present invention employs a novel adaptive dead time, in which the voltage at node M(1) is compared to a 2 volt reference 89 to turn on MOSFET 40 when MOSFET 31 begins to turn off. In particular, Figure 9 shows the shoot thru protection circuit 61 with low side MOSFET 40. The M1, G1 and GND pins of IC/package 33 are also shown. The shoot thru circuitry comprises an R-S flip-flop 95 and a comparator 96 which is a  $V_{DS}$  comparator for MOSFET 40.

[0054] A two volt input to comparator 96 causes a constant ON quiescent signal to be applied to pin G1. A "sleep mode" input is connected to transistor 97 to provide a low power consumption circuit to keep MOSFET 40 in a quiescent ON state. (Note that the same circuitry is used for low side MOSFET 41). Further, a PWM signal is applied to transistor 98 (simultaneously to both low side MOSFETs 40 and 41), but only the inactive high side by will be able forward the signal to pin G1 or pin G2.

[0055] The novel shoot-thru protection circuit of (each leg) of the invention takes advantage of the switching time difference between the low side MOSFETs 40 and 41 and the high side MOSFETs 31 and 32 respectively. Thus, each of the high side MOSFETs 31 and 32 are provided with conventional charge pumps to obtain a gate voltage higher than  $V_{CC}$ . These charge pumps cause the high side MOSFETs to have a slower turn on/turn off time, compared to that of the low side MOSFETs, which are directly in the circuit of Figure 9. Therefore, when IN1 [or IN2] is set high, the signal applied to pin G1 immediately turns off MOSFET 40 well prior to the time that the charge pump circuitry has switched on the corresponding high side MOSFET 31. Thus, no shoot-thru path is formed between MOSFETs 31 and 40. Similarly, when the signal at IN1 is set low, the high side

switch 31 turns off slowly, but the low side MOSFET 40 cannot turn back on until the voltage  $V_{DS}$ , monitored by comparator 96 has reduced to two volts and back to its quiescent ON state.

[0056] Consequently, the novel circuit of Figure 9 defines a self-adaptive dead time circuitry without circuit complexity. Essentially, the R-S flip flop 95 and comparator 96 memorize the request at IN1 (or similarly at [IN2]) for the turn on of high side MOSFET 31; and the comparator resets the memory when it is fully off [eg,  $(M1-GND) < 2V$ ].

[0057] Figure 10 shows the novel soft start circuitry which is contained in the IC within package 33.

[0058] More specifically, Figure 10 shows the resistor 90 and capacitor 91 of Figure 8 and the oscillator 70 and comparator 71 of Figure 7. Resistor 90 and capacitor 91 are externally mounted on a circuit board in an accessible position so they can be replaced by different value devices to change the RC time constant as desired. Also shown are pins  $V_{RC}$ , SS and GND of package 33.

[0059] The circuit of Figure 10 generates the pulse width modulated (PWM) signal for the start-up of the circuit. Oscillator 70 produces a sawtooth output at above 20 kHz which oscillates between about one and about four volts. This sawtooth output is compared to the voltage at pin SS so that kin SS drives a duty cycle from 0% (if SS is less than 1 volt) to 100% (if SS is greater than 4 volts).

[0060] The pulse duration output of comparator 71 then gradually increases, as shown, without need for control by a microcontroller or program. The SS pin is normally at the central point of the RC network 90, 91 powered by the RC pin. Finally a discharged circuit 101 is implemented to reset and hold the SS pin low while the H-bridge is off.

[0061] In operation, when the IN1 pin is set high, low side MOSFET 40 turns of and, later, as previously described, high side MOSFET 31 turns on, and the

discharge circuitry 101 is released. The voltage at pin SS increases slowly, resulting in a smooth duty cycle variation (PWM signal) at the gate of the inactive leg of the low side MOSFET. Therefore, the switching wave form seen by dc motor 30 goes from 0% to 100% duty cycle, offering a stress-free ramp-up to the load on the motor shaft.

**[0062]** The total switching duration of the soft start sequence is 1 to 4 times the time constant of RC circuit 90, 91. Capacitor 91 is discharged through resistor 105 ( $50\Omega$ ) when the H-bridge conduction stops. The capacitor 91 must discharge completely before any new start up. Further, the load on the motor 30 shaft must come to a complete stop before requesting a new start-up sequence. The soft start duration will vary with different applications, depending on the d-c motor characteristics, load, friction and the like, with trade off being made between inrush current limitation and soft start duration. The value of RC can vary from very smooth start in which soft start duration is as much as 10 times the time constant  $\tau$  (for full torque start up) to as low as 2 times the time constant  $\tau$  for low inertia, low torque start up.

**[0063]** Figure 11 shows a portion of the IC logic control circuit 65 of Figure 7, and shows pins DG, IN1 and IN2.

**[0064]** The circuit includes a hysteresis undervoltage lock-out circuit 120 which is connected to  $V_{CC}$  and turns off gates 121 and 122 to prevent turn on of MOSFETs 31 and 32 when  $V_{CC}$  reduces, for example to below 4 volts. The gates 121, 122 are inhibited until  $V_{CC}$  rises to 5 volts when automatic restart can take place.

**[0065]** Also shown in Figure 11 is the sleep mode circuitry including gate 123, hysteresis elements 124, 125, and inverters 126, 127 which switches the entire IC into a low power consumption mode (for example, less than 50 microamperes) when both IN1 and IN2 are zero. Note that both low side MOSFETs 40 and 41 remain ON during the sleep mode.

[0066] Further a non-braking mode is added, as shown in Figure 11, when IN1 and IN2 are both high.

[0067] Finally, the charge/discharge reset signal (reset RC) at gate 128 is generated when the H bridge is off, and whether it is braking or not. The open collector output of the pin DG is active due to the inner high side switch status.

[0068] High side switches 31 and 32 are preferably IPS (intelligent power switch) devices having current and thermal sensing capability. These devices may employ standard vertical conduction MOSFETs with current sensing with laterally displaced thermal monitor elements to measure the die temperature. More specifically, switches 31 and 32 feature co-packed or integrated circuits containing charge pump, over-current protection (shut-down type) status feedback and active clamp capability. Active clamp capability can be useful in certain abnormal conditions, such as an automotive load dump condition.

[0069] Figure 12 shows the MOSFETs 31 and 32 with their protective circuit. Thus a temperature sense device 130 of any desired type provides an output to comparator 130a. If the temperature exceeds a threshold value  $\theta_{th}$ , an output is applied to OR gates 131 and 132. A current monitor circuit, including current mirror circuits 133, 134 for MOSFET 31 and 135, 136 for MOSFET 32 provide inputs to comparators 138 and 139 respectively, which compare the measured current to a threshold value  $I_{th}$  and, if the current exceeds the reference value, applies signals to OR gates 131 and 132 respectively.

[0070] An output from gates 138 or 139 is connected to and operates RS flip-flops 140 and 141 respectively. These produce outputs st1 or st2 which are coupled to the DG pin in Figure 11.

[0071] Figure 12 further shows driver and charge pump circuits 150 and 151 for MOSFETs 31 and 32 respectively. These are also disabled by a measured

current fault or thermal fault by the operation of flip-flops 140 and 141 to cause the current or thermal shut down of the bridge. Note, however, that the low side MOSFETs 40 and 41 remain ON until the reset condition is applied.

[0072] Since the MOSFETs 31 and 32 may have to dissipate energy at the same time (one ON and the other free-wheeling) the thermal protection circuit 130, 130a latches off as soon as the junction temperature of either of MOSFETs 31, 32 exceeds, for example, 165°C, and the fault condition is forwarded to pin DG as described above. The protective circuits are reset when both IN1 and IN2 are low for a minimum time, for example 50 microseconds.

[0073] The above described functions make the device of the invention particularly suitable for d-c actuator applications, as shown in Figure 8. Thus, it offers a "sleep mode" that shorts the d-c motor 30 (the braking mode has IN1 and IN2 both low) and a soft switching ramp up for movement in both directions without any added circuitry. Current shutdown protects the application in case of a short between motor wires or of any motor wire to ground. Further, assuming sufficient cooling of the low side MOSFETs 40 and 41, the entire H-bridge is protected against overtemperature.

[0074] The present invention also embodies a novel layout and thermal control considerations. Thus, in Figure 12, thermal sensor 130 latches off the appropriate high side switch 31 and 32 when its junction temperature reaches a predetermined value, for example, 165°C. This protection arrangement assumes that the junction temperatures of MOSFETs 40 and 41 will always be lower than that of the high side MOSFETs.

[0075] It has been found that a sufficient margin of error to ensure thermal shut down responsive to the high side devices 31, 32 before it is required by the low side devices 40, 41, is that the low side temperature increase  $\Delta T$  should be one half that of the high side devices. That is;

$$R_{DS(ON)LS} \cdot R_{thjals} < 1/2 [R_{DS(ON)HS} \cdot R_{thjahs}]$$

where:

$R_{DS(ON)ls}$  is the on resistance of low side MOSFETs 40, 41;

$R_{DS(ON)hs}$  is the on resistance of high side MOSFETs 31, 32;

$R_{thjals}$  is the junction to ambient thermal resistance of low side MOSFETs 40, 41; and

$R_{thjahs}$  is the junction to ambient thermal resistance of high side MOSFETs 32, 32.

[0076] Note that  $R_{thja}$  depends on packaging and the heat sink receiving this MOSFET. A copper lead frame offers the best thermal and electrical performance. If a PCB is used,  $R_{thja}$  may be decreased by employing a suitable copper plate on the PCB support or other support for the MOSFETs or with suitable heat spreaders and with heat removal through suitably designed connection pins or other means.

[0077] As one example of a fully protected H-Bridge driver of the invention, the circuit was used to drive a dc motor and had the following characteristics:

$R_{DS(ON)}$	-	12m $\Omega$
$V_{CC}$	-	5.5 to 35 V
$I_{CONT}@ 85^{\circ}C$ ambient	-	6.0 amperes
$I_{SHUTDOWN}$	-	30 amperes
Operating Frequency	-	20 kHz



[0078] The absolute maximum ratings, which are sustainable limits beyond which damage to the driver may occur are as follows, with voltages referred to the GND pin; @ a 25°C ambient; symbols with (2), referring to the M2 output:

Symbol	Parameter	Min.	Max.	Units
Vm1 (2)	Maximum M1 (M2) voltage (active clamp)	Vcc-37	Vcc+0.3	V
Vin1(2)	Maximum IN 1 (IN 2) voltage	-0.3	5.5	
Vcc/gnd	Maximum Vcc pin to GND pin voltage	0.3	50	
I in 1 (2)	Maximum IN1 (IN2) current	-1	10	mA
Vg1(2)	Maximum Gate 1 (Gate 2) voltage	-0.3	7.5	V
Vss	Maximum SS voltage	-0.3	5.5	
Vrc	Maximum Vrc voltage	-0.3	5.5	
Irc	Maximum output current of the Vrc pin	--	1	mA
Vdg	Maximum diagnostic output voltage	-0.3	5.5	V
Idg	Maximum diagnostic output current	-1	10	mA
Isd cont.	Diode max. Permanent current (Rth=60°C/W) (1)	--	3.0	A
	(Rth=45°C/W) (1)	--	4.0	
Isd pulsed	Diode max. pulsed current (1)	--	15	
ESD 1	Electrostatic discharge (human body model C=100pF, R=1500Ω)	--	tbd	V
ESD 2	Electrostatic discharge (machine model C=200pF, R=0Ω, L=10μH)	--	tbd	
PD	Maximum power dissipation (Rth = 60°C/W)	--	1.5	W
TJ max.	Max. storage & operating junction temperature	-40	+150	°C
TL	Lead temperature (soldering 10 seconds)	--	300	

Symbol	Parameter	Min.	Max.	Units
V <sub>cc</sub> max	Maximum V <sub>cc</sub> voltage	--	37	V
I <sub>g1</sub> (2) max.	Maximum gate current (T <sub>on</sub> < 5 $\mu$ S)	--	100	mA
I <sub>g1</sub> (2) avg.	Maximum average gate current	--	10	

[0079] The device thermal characteristics are:

Symbol	Parameter	Typ.	Max.	Units
R <sub>th</sub> 1	Thermal junction to amb. Resistance (std footprint 1 MOS on)	60	--	°C/W
R <sub>th</sub> 2	Thermal junction to ambient resistance (1" sq. footprint 1 MOS on)	45	--	

[0080] Typical Operating conditions are as follows:

Symbol	Parameter	Min.	Max.	Units
V <sub>cc</sub>	Continuous V <sub>cc</sub> voltage (2)	8	18	V
V <sub>in1</sub> (2)	High level IN 1 (IN 2) input voltage	4	5.5	
V <sub>in1</sub> (2)	Low level IN 1 (IN 2) input voltage	-0.3	0.9	
I <sub>out</sub> T <sub>a</sub> =85°C	Continuous output current (R <sub>th</sub> /amb<5°C/W, T <sub>j</sub> =125°C)	--	7.0	A
I <sub>out</sub> T <sub>a</sub> =105°C	Continuous output current (R <sub>th</sub> /amb<5°C/W, T <sub>j</sub> =125°C)	—	4.5	
R <sub>in</sub>	Recommended resistor in series with IN pin	10	20	k $\Omega$
R <sub>dg</sub>	Recommended pull-up resistor on DG pin	1	20	
R	Soft-Start resistor	5.0	100	
C	Soft-Start capacitor	0.1	3.3	$\mu$ F

Symbol	Parameter	Min.	Max.	Units
R gate	Recommended gate resistor for Low Side Switch	0	50	$\Omega$

[0081] Finally, the Static Electrical characteristics are, at  $T_j=25^{\circ}\text{C}$  and

$V_{cc} = 14\text{V}$ :

Symbol	Parameter	Min.	Typ.	Max.	Units	Test Conditions
Rds1 on	ON state resistance $T_j + 25^{\circ}\text{C}$	--	9	12	m $\Omega$	$V_{in1,2}=5\text{V}$ , $I_{m1,2}=5\text{A}$
Rds2 on	ON state resistance $T_j + 150^{\circ}\text{C}$	--	16	22		
Vcc oper.	Functional voltage range	5.5	--	35	V	
Vclamp1 (2)	Vcc to M1 (M2) clamp voltage	37	40	48		$I_d=10\text{mA}$ see Figs. 1, 2
Vf1 (2)	Body diode 1 (2) forward voltage	--	0.9	--		$I_d=5\text{A}$ , $V_{in1,2}=0\text{V}$
IM1 (2) leakage	M1 (M2) output leakage current	--	10	50	$\mu\text{A}$	$V_{m1,2}=0\text{V}$ ; $T_j=25^{\circ}\text{C}$ $V_{in1(2)}=0\text{V}$
Icc off	Supply current when off (sleep mode)	--	10	50		
Icc on	Supply current when on	--	8	--	mA	$V_{in1}=5\text{V}$
Vdgl	Low level diagnostic output voltage	--	0.3	--	V	$I_{dg}=1.6\text{mA}$
Idg leakage	Diagnostic output leakage current	--	--	10	$\mu\text{A}$	$V_{dg}=5.5\text{V}$
Vih1 (2) th.	IN1 (IN2) high threshold voltage	--	2.6	--	V	
Vil1 (2) th.	IN1 (IN2) low threshold voltage	--	2.0	--		
Iin1 (2)	ON state IN1 (IN2) positive current	--	25	--	$\mu\text{A}$	$V_{in1,2}=5\text{V}$
Vccuv	Vcc UVLO positive going threshold	--	5	--	V	
Vccuv-	Vcc UVLO	--	4	--		

Symbol	Parameter	Min.	Typ.	Max.	Units	Test Conditions
V <sub>ss+</sub>	SS high level threshold	--	4	--		
V <sub>ss-</sub>	SS low level threshold	--	1	--		
I <sub>ss leakage</sub>	SS pin leakage current	--	0.1	10	μA	

[0082] Figure 13 shows a timing diagram which illustrates the soft start sequence previously described. The three lines of Figure 13 show the voltages at pins IN1 [or IN2]; SS; and [M1-M2] (M1+M2) on a common time base t. Note that the duty cycle modulation at pin M1 follows the increase in the voltage at pin SS, and the modulation period T<sub>ss</sub> is set at about 1-4 RC (time constant).

[0083] Figure 14 shows the active clamp voltage wave forms for the active clamp of Figure 12, at pins IN1 or 2 and M1 or 2, and the current at pin M1 or 2 on a common time base.

[0084] Figure 15 shows the novel protection scheme timing diagram at pins IN1 or 2; DG; M1 or 2 (a current wave shape) and a presumed T<sub>j</sub> on a common time base. When either IM1 or T<sub>j</sub> reach shut down values, the bridge will be turned off.

[0085] Figures 16 and 17 show turn on and turn off conditions at pins IN1 and M1 on a common time base and define various terms previously used.

[0086] Figure 18 shows a timing diagram for motor current versus the voltages at pins IN1; IN2; SS; M1 and M2. The soft start sequence of operation is shown on the M1 and M2 lines; the braking mode is shown with pins M1 and M2 grounded; and the stand-by mode is shown with pins M1 and M2 opened (high).

[0087] Although the present invention has been described in relation to particular embodiments thereof, many other variations and modifications and other uses will become apparent to those skilled in the art. It is preferred, therefore, that the present invention be limited not by the specific disclosure herein.

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